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A Swept Wing Panel in a Low Speed Flexible Walled Test Section

M. J. Goodyer
Vigyan Research Associates, Inc.
Hampton, Virginia

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1. Introduction

There is continuing interest in the testing of sections of swept wings at transonic speeds, particularly as a means towards understanding the three-dimensional development of boundary layers under the influence of pressure gradients, surface curvature and surface texture. This report is concerned with a swept wing panel, the wing having a constant chord and section, without twist and spanning the test section.

Test section boundary interference can play a part in corrupting measurements, the interference arising from the improper shape of the boundary as well as from fluctuating disturbances particularly in the case of a ventilated test section. Both interference effects can be reduced by employing a solid-walled test section with the walls contoured to follow a suitable streamtube past the swept-wing model[1]. For the usual rectangular test sections the wall contouring separates into three tasks:

i) the sidewalls from which the model is mounted, which should adopt identical but rather complex three-dimensional shapes about their respective wing tips,

ii) the top wall, deformed from the flat only in single curvature in the form of a wave swept with the wing,

iii) the bottom wall, similar to the top but adopting, in general, a different wave form.

A streamtube springing from a fixed rectangle at the end of the contraction would therefore have relatively simple top and bottom surface geometries but much more complex sides. In fact one sidewall, that which supports the more upstream end of the wing would, in the case of inviscid flow, completely engulf the wing with a glove, hiding the wing's outline, with the sidewall itself then becoming the model. This is a model thickness effect. The likelihood is, however, that in most regions the glove would be very thin and in these regions much modified by viscous effects. The opposite wall would be identical. All three contours change with change of model or test conditions, with the result that any thought of accommodating such variables appears daunting.

A consequence of leaving the sidewalls flat is, in principle, a need to correct for sidewall images comprising similar wings swept alternately forward and backward. There is evidence[2] that in low speed testing the correction is quite small. The prospect of streamlining the top and bottom walls is simpler in concept, complete streamlining requiring the walls to be deformed only in single curvature.

Following this reasoning it was decided to explore the design and use of an adaptive walled test section for swept wings. The test section would feature plane sidewalls but adjustable top and bottom walls, for an existing low speed wind tunnel. The shapes of flexible walls are controlled by sets of ribs attached to jacks. The principal new feature of this test section was that the ribs were also swept, at the same angle as the wing. This in itself introduces no difficulty until the walls are streamlined when it has to be recognised that flexible walls which have straight edges when flat (or nearly flat, as when aerodynamically straight) are no longer straight viewed from above, but move sideways to some extent. The point is illustrated on Figure 1 which is meant to be self-explanatory. The lines A2 and B2 represent one edge of a flexible wall, straight and streamlined respectively, viewed from above the swept wing. The magnitude of the sideshift had to be investigated to make due allowance during construction, and depends even in low speed testing on a variety of factors such as test section height and length and aerofoil chord, thickness and lift coefficient. Each application must be studied independently. This issue is addressed in the next section of this report which describes a test section designed to use an existing constant chord model.

The purpose of this work was to investigate the design problems, streamlining and its effect on model behaviour, and to compare model data with reference.

2. The Model

A 3-foot span aerofoil model of NACA 0012-64 section which was built in 1974 for adaptive wall work was available for this work. The chord is 5.4 inches and the model was calibrated in LTPT at several Mach numbers close to 0.1. The depth of LTPT (7½ feet) allows wall interference to be

neglected. The model was subsequently used in a number of investigations in the U.K. and the U.S.A.

Its usefulness derived from the fact of pre-calibration, and its relatively large span in relation to the wind tunnel which was proposed for use which had a width of 1 foot. The model could be swept to substantial angles and still penetrate the sidewalls: 40° was chosen, arbitrarily. In the first tests, reported here, the angle of attack was fixed at a nominal 6° measured normal to the leading edge.

Around the mid-span of the model are 39 pressure orifices positioned at the leading edge and at approximately 5% chord intervals over the two surfaces.

3. The Wind Tunnel

This is a low speed open-return type with approximately atmospheric stagnation conditions. As originally built it had a 1-foot square test section, but for adaptive-wall work the contraction is modified to supply air to a test section 1 foot wide and 6 inches deep at its upstream end.[3] The maximum speed which can be reached in this form is about 115 ft. per second.

4. Test Section Design

The two flexible walls forming the top and bottom of the test section are anchored at their upstream ends to the contraction. The walls are PVC sheet and were cut with sufficient edge-clearance to allow for the sideshift anticipated during streamlining. The significant parameters for the sideshift calculations include the ratio of test section height to model chord (1.1), the ratio of test section streamlined length to model chord (~5.1 measured at right angles to leading edge), the maximum lift coefficient (~0.7 at 10°) and the point of rotation of the model (model rotates about its mid chord position at mid test-section height, 2.8 chords downstream of the mid-span of the anchor points, measured normal to the leading edge).

The sideshift is a maximum for the top wall with the model at positive incidence and computations showed that the maximum sideshift for this wall

was a mere 0.02 inches. This is below the level of clearance which would be provided between a sidewall and flexible wall of conventional design and therefore an allowance for sideshift was judged not to be necessary.

Components of our original adaptive wall test section (in its 1976 form[3]) were used as far as possible including the manually operated jacks and their supports. This dictated the positions of the ribs and a streamwise section through the centreline of the resulting test section is shown on Figure 2. The ribs are of course swept and the plan view of one flexible wall on Figure 3 shows the ribs, wing, wall static pressure orifices and anchor point. The walls were of 1/16 inch thick PVC sheet, with ¼-inch wide aluminium ribs bonded directly. At their downstream ends the walls terminated at extensions which were not streamlined in these tests, of streamwise length 14.7 inches. The pressure tappings on the wing were positioned roughly mid-way across the test section.

The reference static pressure was taken from the sidewall at mid height at a point one-inch aft of the anchor point, and the total pressure from a sidewall-mounted pitot tube just downstream. Pressures were measured on inclined-tube alcohol manometers.

The model was first mounted at a fixed angle of attack but is now in sidewall trunnions which allow the angle to be varied, at present through the range $\pm 12^{o}$ which happens to be sufficient to take this model through stall.

5. Streamlining

As is normal practice this operation is based on measurement of the wall static pressures and the reference pressures. For a swept wing the measured pressure coefficients must be converted into resolved coefficients, that is equivalent coefficients in the component of flow normal to the leading edge. The conversion from a measured pressure coefficient C_p' to a resolved coefficient C_p is

$$C_p = \frac{C_p'}{\cos^2\Lambda}$$

where Λ is the sweepback angle.

The resolved pressure coefficients were applied directly to the original predictive wall adjustment strategy[4], using jack spacings measured at right angles to the wing leading edge and yielding vertical jack displacements which require no further correction for sweepback. The algorithm was found to converge satisfactorily in about four iterations with the model set at 6 degrees angle of attack relative to the normal component of the free stream. In this exercise, however, the streamlining was continued for two more iterations.

Figure 4 shows, in its top half, the measured resolved pressure coefficients along the walls with them set straight and also streamlined. Also plotted are the computed pressure distributions along the imaginary sides of the walls following streamlining, showing excellent agreement with measurements confirming that the walls are unloaded. The shapes taken up by the two walls are plotted in the lower half of the figure showing the usual upwash upstream followed by separation for wing thickness and wake.

One measure of the quality of streamlining which has proved reliable is E, the average over the jack set of the modulus of the differences in pressure coefficient between real and imaginary sides. The history of the convergence as summarised by E is shown on Figure 5 where it is seen that E dropped below 0.01 (an acceptably low value) for both walls on the 4th interation. Iteration zero is the straight-wall case. Beyond about 4 iterations it appears that E is not likely to reduce significantly. The definition of E does not allow it ever to reach zero in the presence of experimental error.

Figure 6 is a view of the test section after streamlining, taken from just under the leading edge. The wing penetrates clear plastic sidewalls where it is supported in turntables. Tape is attached to the top wall to help show the wave in this wall running parallel to the wing. Swept ribs and jack components for the bottom wall are clearly visible.

6. Model Data

In this series of tests the model was not fitted with any form of transition strip and was tested at a reference airspeed of 77.6 ft./sec. which is 59.4 ft./sec. when resolved normal to the leding edge. The pressure

coefficients measured and resolved are shown on Figure 7 with the walls straight and streamlined. The continuous line highlights the streamlined-resolved pressure distribution which is to be compared with reference data. The usual reduction is seen in the magnitude of $-C_p$ over the suction surface brought about by streamlining, but also shown on this figure is the magnitude of the effect of resolving measurements into the normal component of flow. The streamlined distributions were taken on completion of iteration 6.

The LTPT reference data was taken with transition strips attached near the leading edge on both surfaces, and at several different velocities relative to the leading edge but all above the value used in these experiments. The closest reference data in terms of air speed was taken at about 98 ft./sec. and is used here for comparison. Therefore the four significant differences between the two tests are airspeed, surface roughness, sweepback and test section height. The former two may not be very important, the latter differences are intended to be corrected by wall streamlining.

A comparison of the two data sets is shown on Figure 8. There is generally excellent agreement except at 5% chord. The transition strips used in obtaining reference data were attached at this position and may account for some of the disparity.

7. Discussion

The immediate aims of the investigation appear to have been met; that is the design and operational issues have been addressed and the limited amount of experience so far accumulated suggests no major problem, at least when designing for and using moderate values of lift coefficient. Convergence to streamlines is reasonably rapid and after streamlining there is good agreement with reference data despite the differences in test conditions. The differences, aside from the obvious change of sweepback angle, include the absence of transition strips on the swept wing with the use of a lower speed hence Reynolds number. In view of this, the agreement between the two aerofoil pressure distributions is perhaps surprisingly good considering that they were taken in two vastly different wind tunnels (the reference data in a tunnel having 45 times the flow area in its test section than this adaptive wall

test section) with possible influences from differing turbulence levels and precision of measurement of angle of attack.

A design feature which arose from the use of some existing hardware but which would be avoided in future is visible on Figure 3. Rib 1, at its upwind end, is too close to the anchor point with the result that the walls adopt an inappropriate shape in responding to the upwash in this area induced by a lifting model.

Following this work it would seem reasonable to expect the wall flexing system to accommodate the variables of angle of attack (as long as the model penetrates the side-walls to some extent), Mach and Reynolds numbers, model size and section. While this already is a longer list than might have been expected at first, the remaining variable of significance is sweepback angle. There has been no provision for such variation in the design of the test section, but the available options seem to be:

- allow the ribs to pivot about an axis centered on the centreline pressure tapping, to match the sweep of the rib with the sweep of the wing. Difficult in practice.

- manufacture several walls with various fixed sweepback angles, say 0, 20°, 40°. The maximum mismatch between the sweeps of the wall and model would then be 10° and perhaps acceptable.

Sidewall shaping has been ignored on the argument that in low speed tests it is not important, although this is not the case as speeds approach sonic. A fully adaptable test section for testing swept wings at such speeds could feature top and bottom wall treatment of the kind introduced in this report, but coupled with some sidewall treatment which must be the subject of separate study.

8. Conclusions

1. Flexible top and bottom walls, controlled by jacks attached to swept-back ribs, have been shown to effectively reduce wall interference with a

swept-back wing panel when the walls are streamlined according to standard procedures.

2. Testing will be extended to include variations in angle of attack of the wing, with transition strips applied and at a higher airspeed in order to accumulate more experience, at conditions more closely reproducing those of the reference test data.

3. A useful investigation would be to study the effects of mismatch between the sweepback angle of the wall wave and that of the wing.

4. An application to transonic testing would require consideration of sidewall streamlining.

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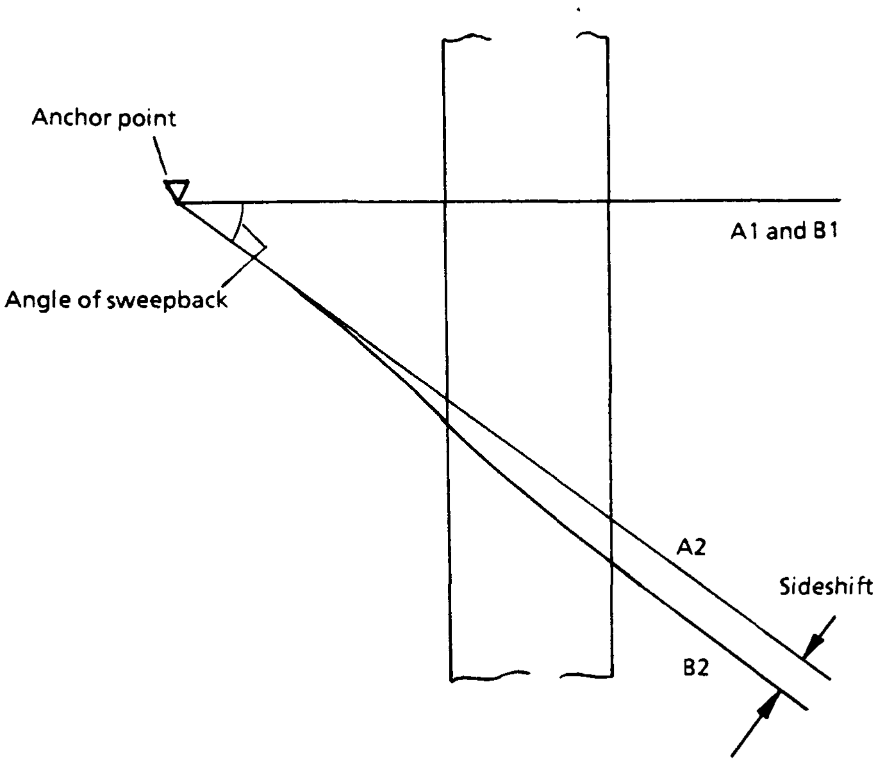
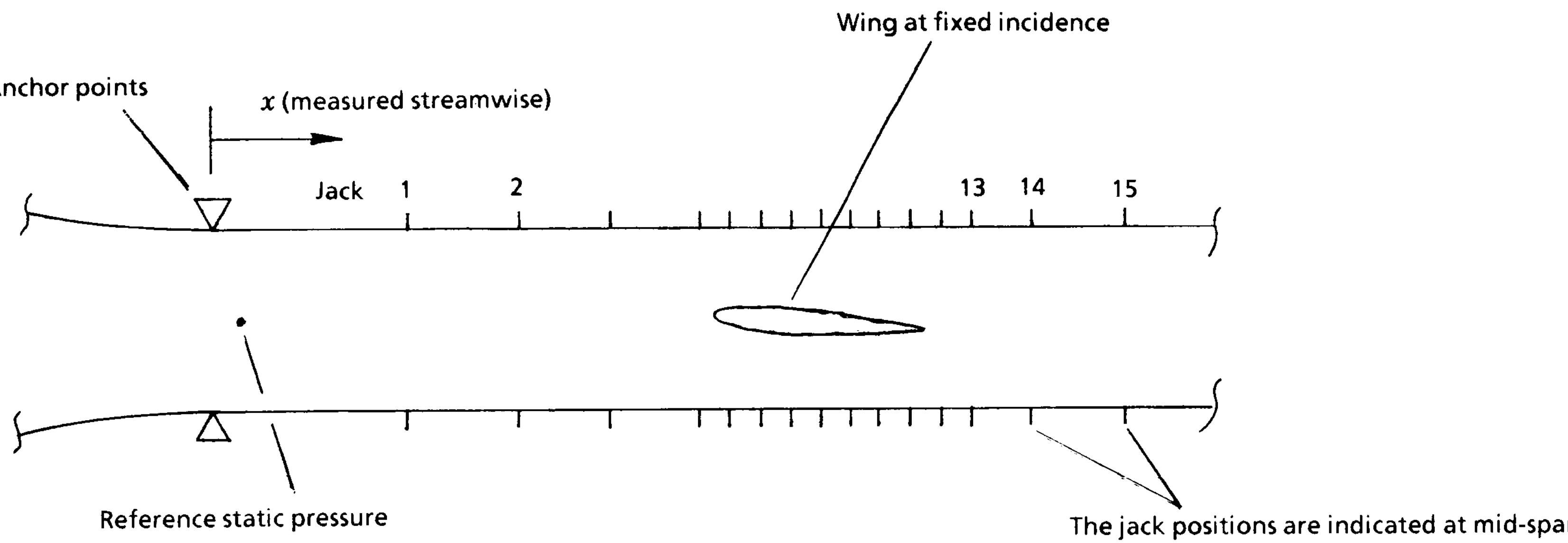
4. Wolf, S.W.D. and Goodyer, M.J.: **Predictive Wall Adjustment Strategy for Two-Dimensional Flexible Walled Adaptive Wind Tunnel. A Detailed Description of the First One-Step method.** Department of Aeronautics and Astronautics, University of Southampton Memo AASU 85/12, January 1986.

i) Side view of wing looking spanwise, showing straight wall (A) and streamlined wall (B)



ii) Two lines are drawn on the flat wall A, at right angles to the leading edge (A1) and parallel to the yawed free stream (A2). The wall is then streamlined to contour B. In this view line A1 → B1 which is coincident. Line A2 is displaced laterally to B2 by a maximum amount shown as the sideshift.

FIGURE 1. SKETCH ILLUSTRATING THE SIDESHIFT WHICH OCCURS IN STREAMLINING A WALL AROUND A SWEPT WING



Jack	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
x (inches)	6	9.75	12.75	15.75	16.75	17.75	18.75	19.75	20.75	21.75	22.75	23.75	24.75	26.75	29.75

Wing leading edge at x = 16.25

FIGURE 2. SWEPT WING PANEL: SKETCH OF CENTERLINE GEOMETRY OF TEST SECTION WITH JACK POSITIONS

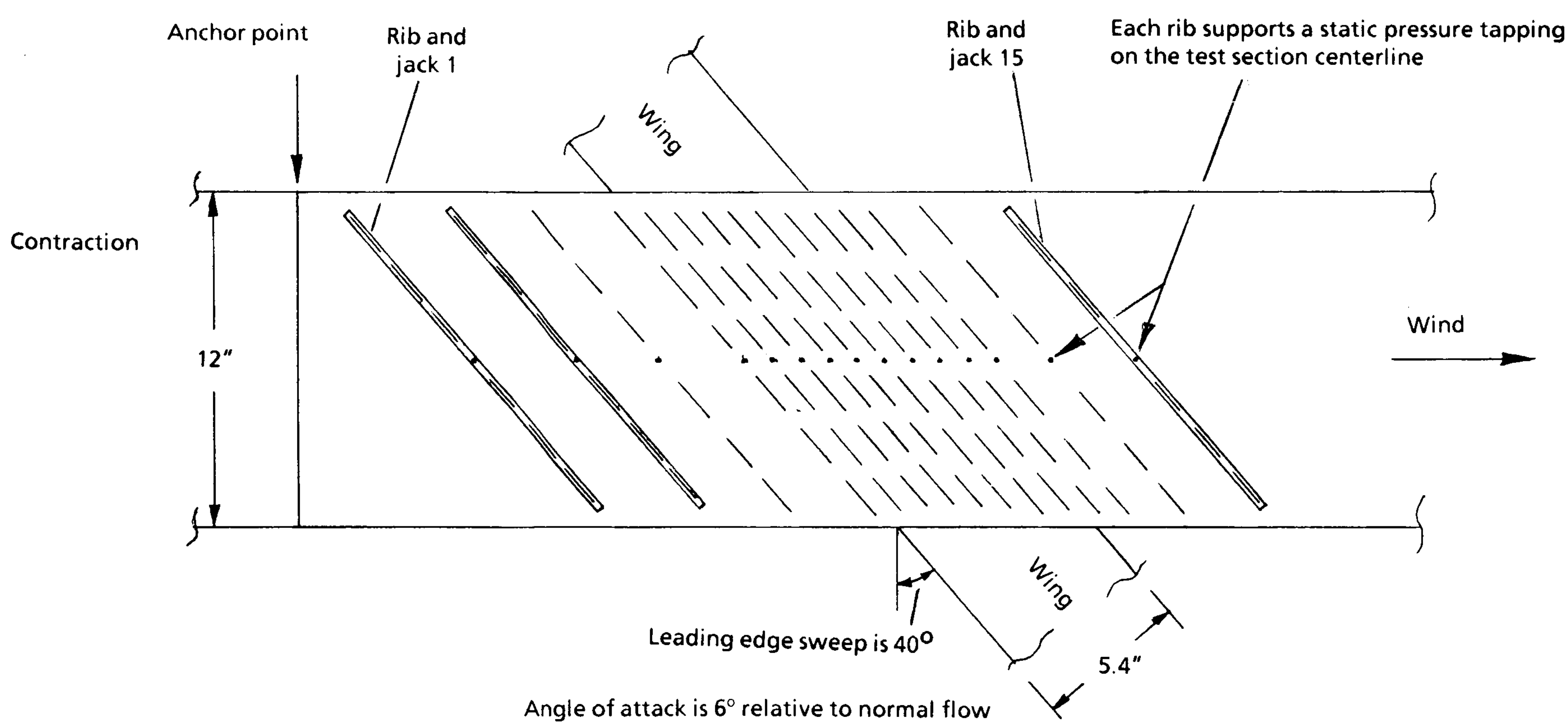


FIGURE 3. SWEPT WING PANEL: SKETCH OF FLEXIBLE WALLS AND MODEL IN PLAN VIEW, SHOWING SWEPT WALL-STIFFENING RIBS

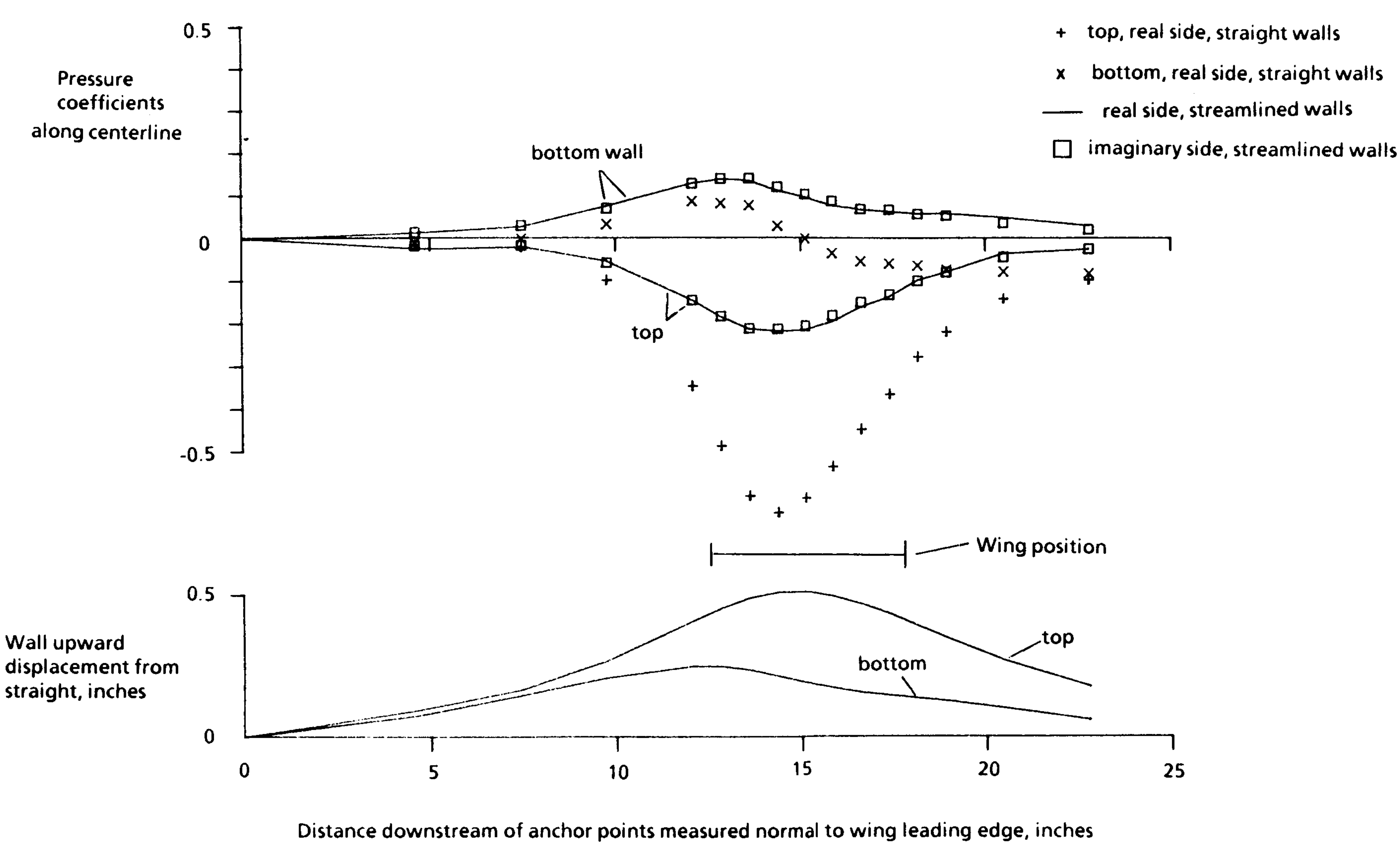


FIGURE 4. SWEPT WING PANEL: PRESSURE DISTRIBUTIONS WITH STRAIGHT AND STREAMLINED WALLS, AND WALL CONTOURS

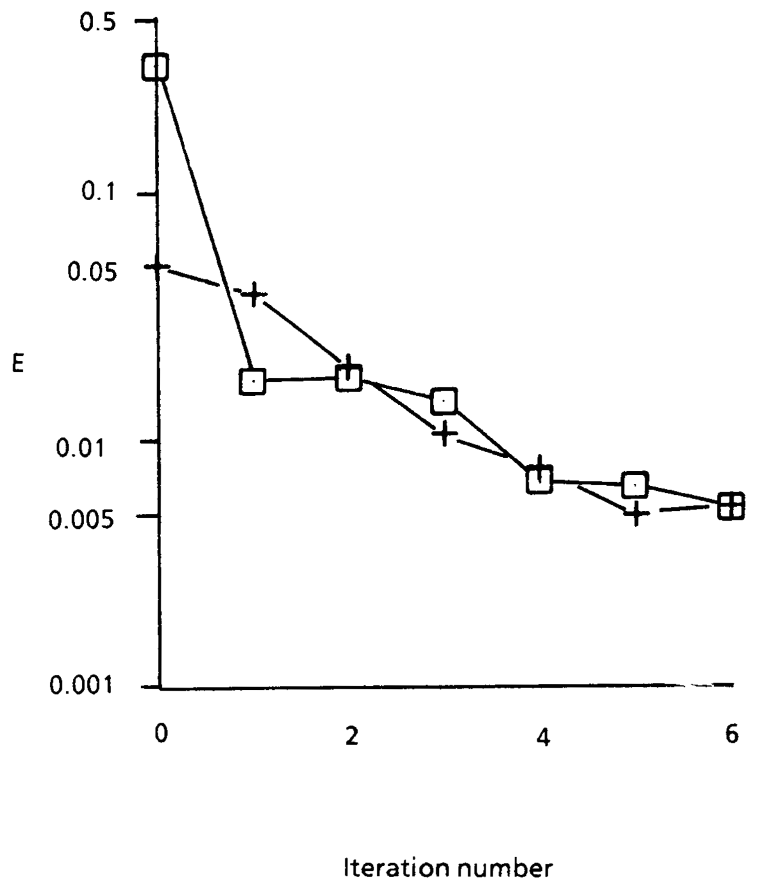


FIGURE 5. THE CONVERGENCE OF WALL LOADING PARAMETER E

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OF POOR QUALITY

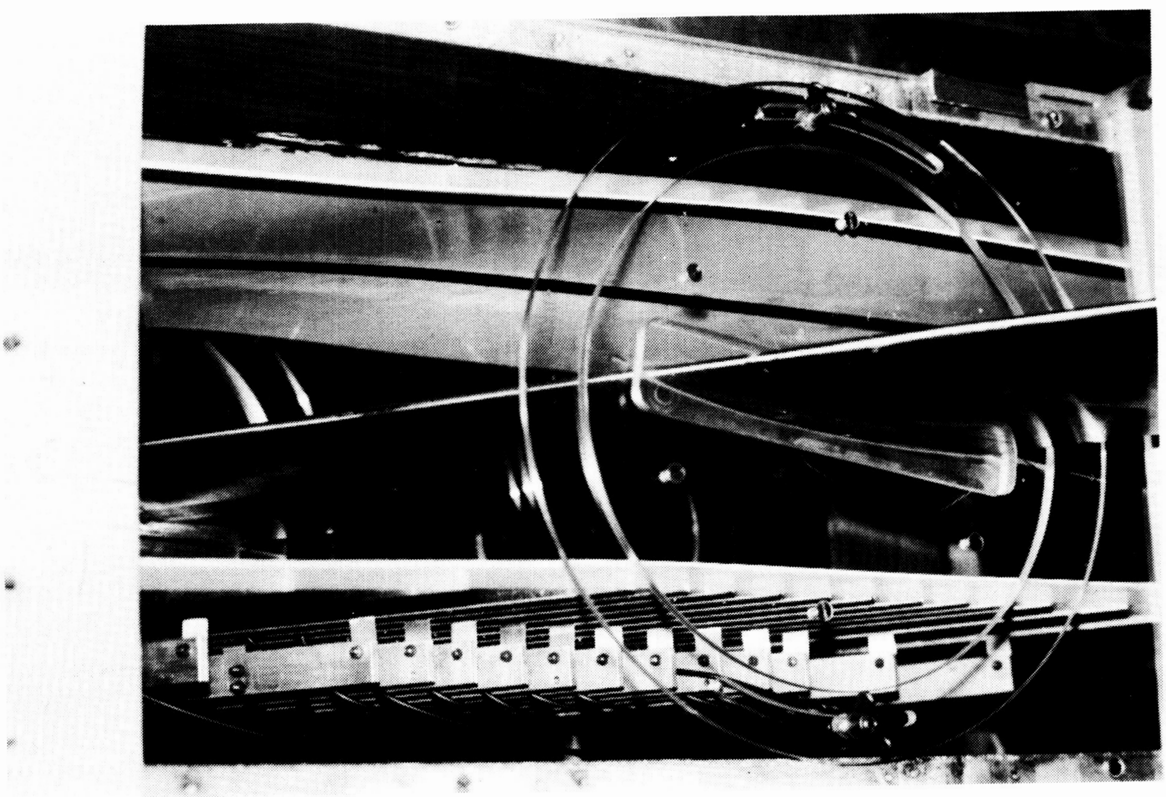

FIGURE 6. A VIEW OF THE TEST SECTION AFTER STREAMLINING

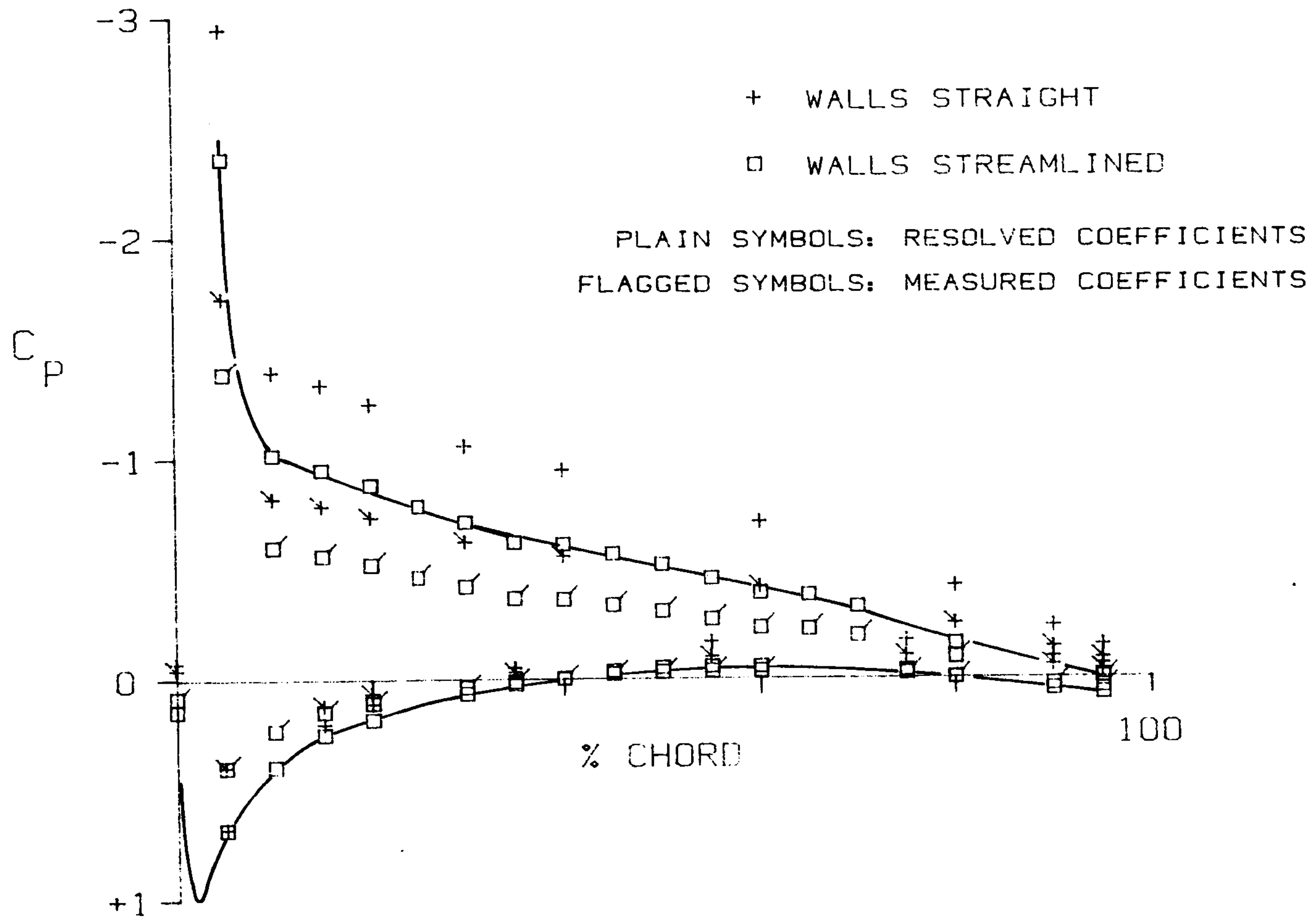

FIGURE 7. SWEPT WING PANEL: PRESSURE DISTRIBUTIONS BEFORE AND AFTER WALL STREAMLINING. NACA 0012-64 SECTION SWEPT AT 40°

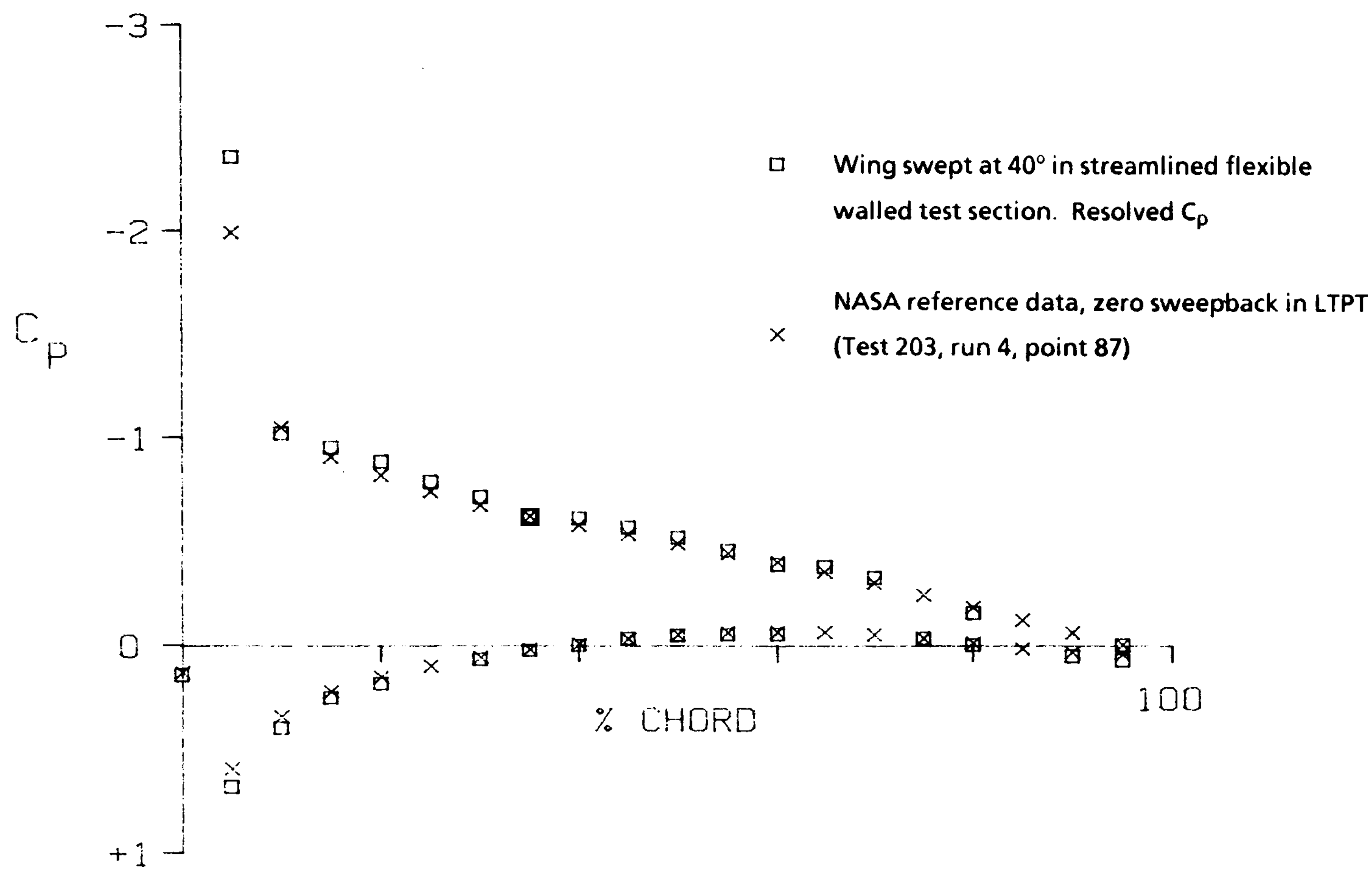

FIGURE 8. COMPARISON BETWEEN WING PRESSURE DISTRIBUTIONS AT 6° INCIDENCE

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16. Abstract

The testing of two-dimensional airfoil sections in adaptive wall tunnels is relatively widespread and has become routine at all speeds up to transonic. In contrast the experience with the three-dimensional testing of swept panels in adaptive wall test sections is very limited, thus comprising some activity in the 1940's at NPL, London.

The current interest in testing swept wing panels led to the work covered by this report. This describes the design of an adaptive-wall swept-wing test section for a low speed wind tunnel and gives test results for a wing panel swept at 40°. The test section has rigid flat sidewalls supporting the panel, and features flexible top and bottom walls with ribs swept at the same angle as the wing. When streamlined, the walls form waves swept at the same angle as the wing. The C_L - curve for the swept wing, determined from its pressure distributions taken with the walls streamlined, compare well with reference data which was taken on the same model, unswept, in a test section deep enough to avoid wall interference.

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